Use of Dissimilar Metals in Building Façades

Testing the common knowledge

by Jeffry J. Ceruti, PE

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DESIGNERS HAVE LONG BEEN AWARE OF THE NEED TO SEPARATE DISSIMILAR METALS. THIS REQUIREMENT FREQUENTLY APPEARS IN PROJECT SPECIFICATIONS FOR SHEET METAL AND OTHER TRADES, BUT INDUSTRY REFERENCES FOR GALVANIC CORROSION ARE INADEQUATE FOR TODAY'S USE OF ARCHITECTURAL SHEET METAL IN FAÇADES AND ROOFS. THIS MAKES IT DIFFICULT TO ASSESS THE REAL RISK OF COMBINING DIFFERENT METALS.

Architectural design of façades has become more complex, and buildings now commonly include multiple materials that may be incompatible over the long term. Even relatively standard rainscreen wall systems, such as aluminum panels supported by galvanized steel framing, can create durability issues. Runoff or dripping from roof and gutters over the façade, or projected ledges covered with metal, may also create potential for galvanic corrosion and staining.

This article reviews the issues associated with galvanic corrosion in architectural applications, and presents initial findings of atmospheric corrosion testing between metals commonly used in building façades.

Background

Galvanic corrosion is an electrochemical process that occurs when two different metals come in contact in the presence of an electrolyte. This process is the basis for standard battery construction. In this situation, an electric charge is produced, and the metal with the lower voltage potential (*i.e.* the anode) in a given electrolyte solution will corrode preferentially to the metal with the higher voltage potential (*i.e.* the cathode).

The anode's corrosion rate is accelerated beyond that which normally occurs if the cathode was not present.

In batteries, the electric charge is depleted when the anode metal is consumed. With respect to architectural applications, accelerated corrosion may cause structural damage of the anodic metal or aesthetic issues. It is important to note the corrosion potential (or voltage potential) created between two metals depends on the electrolyte used—the same two metals may act vastly different in varying electrolyte solutions.

ASTM International G 82, *Standard Guide for Development and Use of a Galvanic Series for Predicting Galvanic Corrosion Performance*, provides a method for developing a series for any electrolyte of interest. The guide includes two galvanic series charts as examples, but both were developed for metals in seawater; the precautions note each series is specific to the environment for which it is compiled, and should not be used to predict performance in other environments.

Standard galvanic series charts have been available for many years. They provide general guidelines for compatibility of metals. However, many of the

Toronto's Art Gallery of Ontario (AGO) marks the first Canadian building by native son, Frank Gehry. Among its many design features is the striking use of blue titanium and other metals. Use of dissimilar materials can have an impact if corrosion is not taken under consideration.

Photo courtesy Peter Saunders

Condensation collected in the skylight gutter system and drained onto the copper roof, as designed. However, these portions remained a bright red while the rest turned dark brown.

commonly available galvanic series charts were developed by or for the U.S. Navy in the 1940s. The Navy, for good reason, used seawater as the electrolyte because it was interested in metals used in ship construction. Chloride ions can significantly accelerate the corrosion of most common metals; in a galvanic situation, corrosion of the anodic metal can accelerate even faster.

Figure 1

Corrosion occurred on this copper roof where condensation dripped from an aluminum skylight, while the remainder of the roof turned dark brown due to the influence of normal weathering.

Images courtesy Simpson, Gumpertz, and Heger

Figure 2

For the test assemblies in suburban Massachusetts, different pieces of metal are loose-locked together and mounted on wood frames set at a 10-degree slope, with the lock 'shingled' to shed water.

Galvanic series charts for atmospheric conditions, without chlorides, are not generally available. Consequently, designers and their consultants have been making decisions on sheet metal compatibility for buildings based on galvanic series information developed using seawater. However, unless the project is very close to the shore, chlorides are not present in most architectural applications. Since the atmospheric exposure of a building may be significantly different than an ocean exposure, the actual performance of metals on buildings could be quite different than the standard galvanic charts may predict.

Further, the available galvanic series charts incorporate many high-end alloys used for industrial or marine applications, but exclude the materials and coatings normally employed in architectural applications. Many newer metal alloys have not been tested for galvanic action. The charts also do not describe the severity of galvanic corrosion or the potential for staining between different metals or materials.

Atmospheric testing

The lack of appropriate industry references first came to this author's attention in the early 1990s, after observing a copper roof suffering from corrosion beneath an aluminum skylight. Condensation collected in the skylight gutter system and drained onto the copper roof, as designed. However, the copper in these locations remained a bright red color while the remainder of the roof had begun its normal oxidation process, turning dark brown after a few months of exposure (Figure 1). In reviewing various galvanic series charts, the consensus was copper would not corrode preferentially to aluminum, because aluminum was far more 'active' than copper. The standard charts did not predict the corrosion pattern.

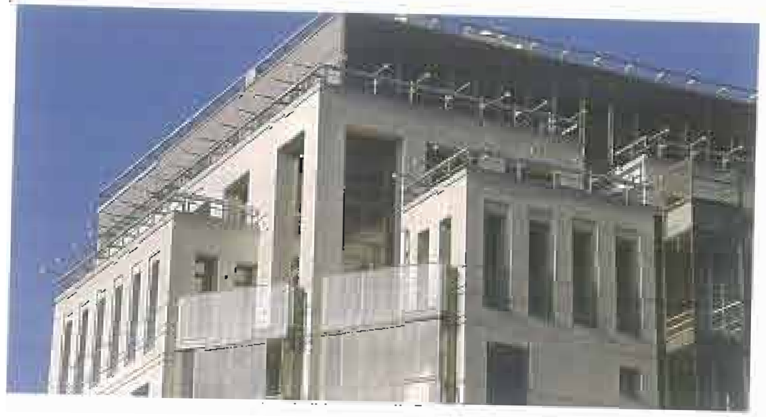
In 2000, this author's firm constructed sample panels on a roof in suburban Massachusetts to assess this further. These specimens were then (and continue to be) exposed to atmospheric conditions to evaluate the potential for galvanic action and staining between commonly used sheet metal materials. The sample panels included the following:

- aluminum;
- aluminum with clear anodized coating;
- aluminum/zinc-alloy-coated steel (Al/Zn steel);
- copper;
- galvanized steel;
- lead-coated copper;
- stainless steel, Type 304;
- tin/zinc-alloy-coated copper; and
- tin/zinc-alloy-coated stainless steel.

The test assemblies comprise 305 x 305-mm (12 x 12-in.) pieces of each type of sheet metal, formed with a 12.7-mm (0.5-in.) hem on one side of every piece. Different pieces of metal are loose-locked together and mounted on wood frames set at an approximately 10-degree slope, with the lock 'shingled' to shed water (Figure 2). Two samples were made for every combination of the different metals tested, alternating the 'upper' and 'lower' sheet orientation. Before installation, each specimen was measured, weighed, and identified.

The test panels and orientation do not meet a standardized test method, since no relevant method was available. Also, the test is not intended to meet the ideal or controlled conditions available in a laboratory, but to better reflect the real-world environment and all its variables.

Architectural façades have become more complex. Buildings now commonly include multiple materials that may be incompatible over the long term. With current data lacking, further research is needed.



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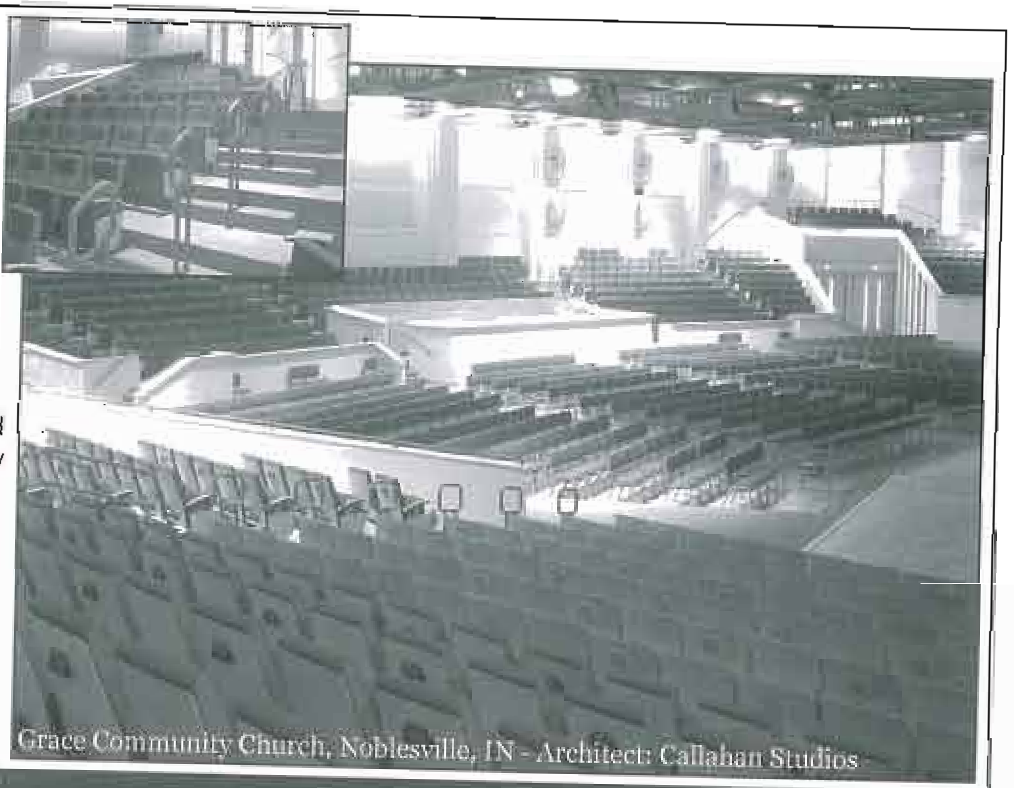


Figure 3

Runoff from stainless steel caused a portion of the copper panel to remain bright and shiny, indicating corrosion.

Figure 4

Stainless steel over lead-coated copper corroded portions of the lead. It caused staining and corrosion on most samples.

Many factors can affect the corrosion rate of metals on buildings, including rainfall amount, temperature, solar gain (*i.e.* exposure), airborne pollutants, and even the presence of birds in the area (they may drop corrosive feces onto the building). Therefore, while this atmospheric test does not use seawater as an electrolyte, it still represents only the local environment—other locations may produce somewhat different results.

Another consideration for galvanic corrosion is the effective area involved between the two metals. If the noble metal has a larger surface area than the active one, then corrosion of the active metal increases more significantly than if the areas were equal. Conversely, if the active metal has a larger surface area, then it may not corrode preferentially to the noble metal. For this reason, more noble materials should generally be selected for smaller pieces of an assembly, such as using stainless steel fasteners with aluminum parts. The test panels were all made the same size to avoid any area effects on the corrosion.

Interim test results

After eight years of exposure, definite patterns emerged in the test samples. Staining and corrosion is occurring on many of the lower samples due to runoff from the upper pieces. Further analysis of samples is needed to identify the elements observed in the stains and to verify whether staining represents actual material loss, or if materials are deposited on the lower sheet.

Type 304 stainless steel, when in its naturally passivated state, is clearly the most noble of the metals tested and has caused staining and corrosion on all samples, except those with aluminum surfacing. Stainless steel draining over copper caused a portion of the copper to remain bright and shiny, indicating corrosion (Figure 3). Stainless steel over lead-coated copper corroded portions of the lead (Figure 4).

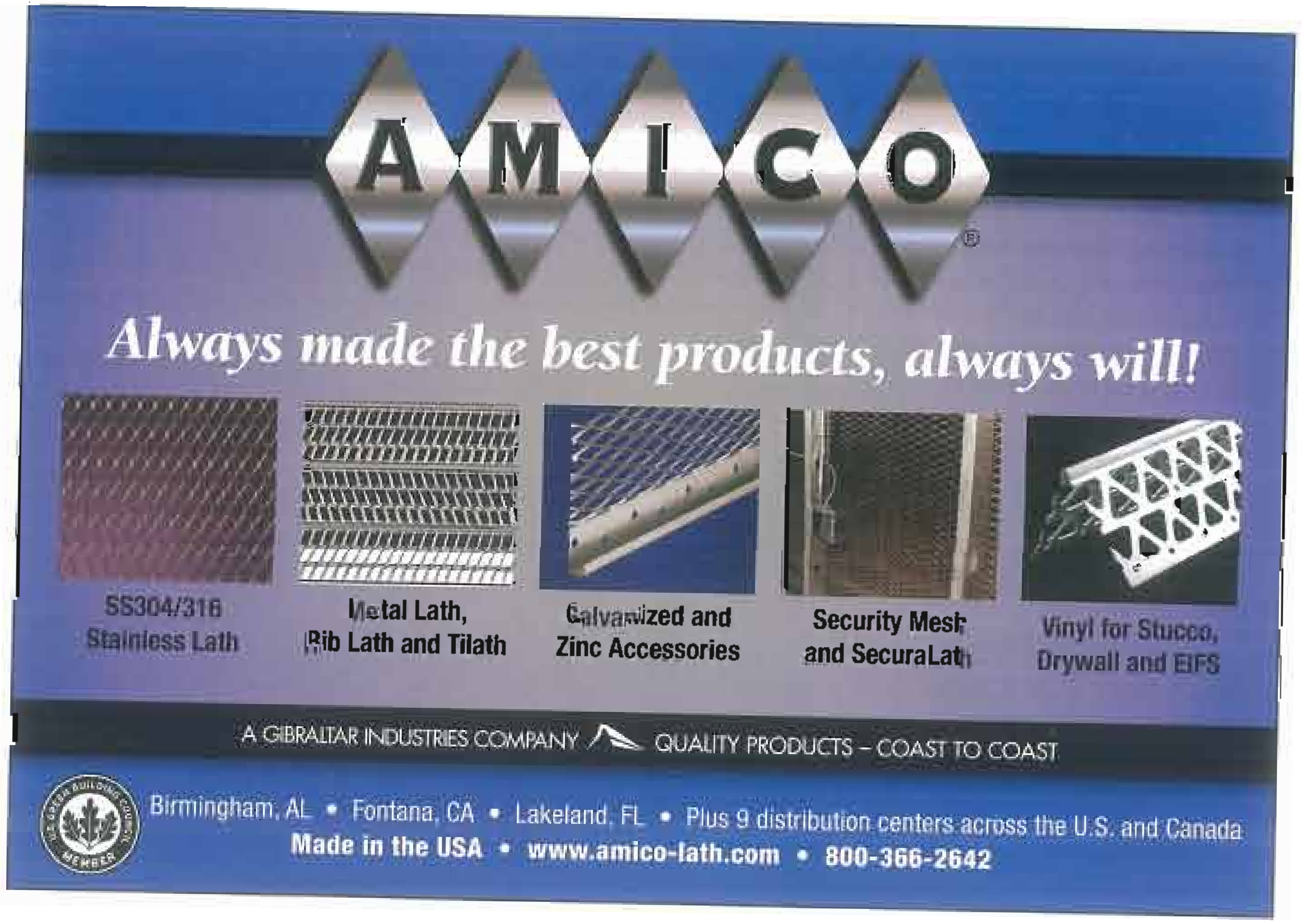
Stainless steel over galvanized steel has caused severe corrosion of the zinc coating and significant rusting of the steel base metal—this reaction was predicted by galvanic series charts, which show stainless steel as a noble metal and zinc as a highly active metal. Stainless steel draining over tin/zinc-coated steel and copper caused significant white/gray staining on both pieces, indicating initial corrosion of the protective coating (Figure 5). However, stainless steel draining over aluminum, anodized aluminum, and Al/Zn-coated steel produced only a minor black stain at the edge of the lock, which may be indicative of an aluminum oxide formation.

Meanwhile, none of the other metals are causing notable staining or corrosion of stainless steel when used as the lower piece, except for some minor staining at the interlock that may result from a corrosion process within the lock.

As indicated in galvanic series charts, copper is also a noble metal, and has corroded the zinc coating and caused red rust on the galvanized steel panel.

Figure 5

Stainless steel draining over tin/zinc-coated steel and copper caused white/gray staining on both pieces, indicating initial corrosion of the protective coating.



> Having stainless steel draining over tin/zinc-coated steel and copper caused significant white/gray staining on both pieces. This indicates the initial corrosion of the protective coating.

Heavy black streaking occurred on the lead-coated copper sheet below copper (Figure 6), and copper also caused staining on the tin/zinc-coated metals and some green staining on the aluminum piece. Copper over the Al/Zn-coated steel resulted in severe coating loss and rusting of the steel base (Figure 7).

Unlike stainless steel, however, all the other metals cause at least some minor gray staining on the lower copper sheet. This may be from deposits of the upper metal onto the copper below or, in the case of galvanized steel and Al/Zn-coated steel (Figure 8), due to corrosion product within the lock that flows onto the copper.

Aluminum caused some definite gray staining on the copper (Figure 9, page 102), but not the bright shiny copper staining observed at the skylight situation years ago. This suggests a difference in the environment or the corrosivity or concentration of water flow.

Aluminum and anodized aluminum as the upper sheet both caused corrosion of the galvanized steel sheet, staining and corrosion of the tin/zinc coating pieces (Figure 10, page 102), and a shiny staining on lead-coated copper. However, on the lower sheet, the anodized aluminum was not affected by any other metal, while the aluminum sheet had black stains where below stainless steel, galvanized steel, and the tin/zinc sheets. This difference shows the heavy aluminum oxide created in the anodizing process helps protect the metal from staining and corrosion.

Figure 6

Heavy black streaking occurred on the lead-coated copper sheet below the copper.

Figure 7

Copper over the aluminum/zinc-coated steel resulted in severe coating loss and rusting of the steel base.

Figure 8

Corrosion product occurs within the lock between aluminum/zinc-coated steel and the copper.

The reaction between lead-coated copper and Al/Zn-coated steel is severe—red rust has occurred at the lock of both sample orientations, indicating failure of the Al/Zn coating and corrosion of the base steel within the lock (Figure 11, page 104). When oriented on the lower sheet, the lead coating is affected by the Al/Zn coating and has a shiny gray streak with black staining. Lead-coated copper has caused corrosion of the galvanized steel, resulting in red rust at the lock area. A faint white stain occurred on the tin/zinc-coated metal below lead-coated copper.

Corrosion incompatibility with dissimilar materials is more prevalent than most realize. Even something as innocuous as metal panels of one type supported by framing of another can yield durability issues.

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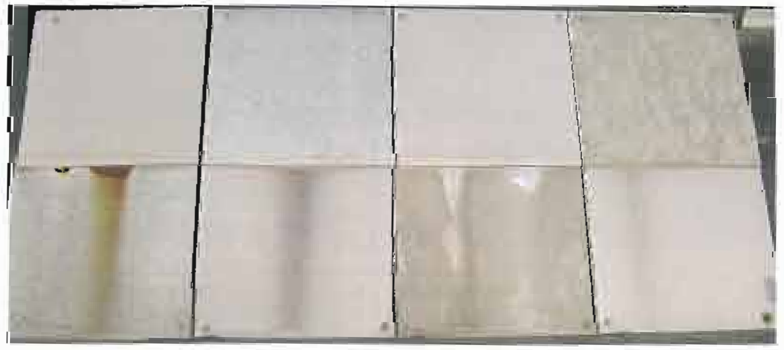
Figure 9

Aluminum and stainless steel caused corrosion or definite gray staining on copper.

Figure 10



Aluminum caused corrosion of the galvanized steel sheet (left), and staining and corrosion of the tin/zinc coating pieces.

Al/Zn-coated steel has also corroded the galvanized steel panel, causing a red rust spot below the lock. Additionally, it has led to white staining and corrosion of the tin/zinc-coated sheets—but to a lesser degree than some of the other metals.

The tin/zinc metals have created minor shiny stains on the lower lead-coated copper panels, but have not caused staining of any other materials. So far, this coating is the only metal to not cause significant corrosion of galvanized steel.

Discussion

Some of the observations discussed in this article, such as the severe corrosion of zinc coating on galvanized steel, might have been predicted by reviewing standard galvanic series charts—zinc is a highly 'active' metal prone to corrosion in galvanic situations. However, other interim results could not be predicted, and the relative severity of the staining and corrosion patterns can help guide decisions on the selection of materials.

One surprise is the performance of aluminum in these tests. An active metal in galvanic tests based on seawater, aluminum should show more significant staining and corrosion when used as the lower sheet. To date, these atmospheric tests show aluminum is not only resistant to significant galvanic corrosion, but can also cause staining and corrosion of some other metals and should be separated accordingly.

Performance of the Al/Zn-coated steel, which is typically not included in galvanic series charts, appears to be similar to aluminum; the Al/Zn alloy is approximately 80 percent aluminum by volume or surface area, so it is not too surprising to see this trend. However, in combination with copper and lead, the Al/Zn coating suffers from heavy staining and corrosion whereas aluminum does not. This may indicate copper and lead are reacting with the zinc-rich phase of the Al/Zn alloy coating, causing premature deterioration.

The tin/zinc coating on stainless steel and copper is a relatively new alloy also not included in galvanic series charts. The tests show tin/zinc is affected by all other metals except galvanized steel and lead-coated copper. This indicates the alloy is a highly active metal. In an actual installation, once the tin/zinc coating is fully deteriorated, the underlying

To gain deeper insight into potential problems with corrosion and dissimilar metals, this author's firm constructed sample panels on a roof in suburban Massachusetts to assess effects.

Figure 11

When pairing aluminum/zinc-coated steel with lead-coated copper, red rust occurred at the lock of both sample orientations, indicating failure of the aluminum/zinc coating and corrosion of the base steel within the lock.

Many factors can affect the corrosion rate of metals on buildings, including rainfall, temperature, solar exposure, airborne pollutants, and even bird feces.

stainless steel or copper should function much like the uncoated products. Consequently, galvanic action may create coating performance and aesthetic issues in the field, but may not result in through-corrosion of the base metal. This is unlike galvanized steel, where corrosion of zinc allows the underlying carbon steel base metal to corrode when exposed to the elements.

Conclusions

As the trend in architectural building design continues to explore the boundaries of what is possible to build successfully, different materials more commonly come in contact or drain over one another within the same building façade. Choices for façade materials have expanded beyond the traditional types used in the past, and now include some materials with short performance track records. As this trend continues, decisions on material selection for building enclosures become increasingly important for both performance and aesthetics, particularly where one material may drain or drip onto a different one.

As different types of metals are incorporated into building façades for performance and aesthetics, design/construction professionals need to be aware of the effects of corrosion processes. Unfortunately, scant industry resources exist. With regard to naval guidelines, atmospheric exposure of a building may be significantly different than an ocean exposure.

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Based on interim observations after eight years of atmospheric exposure in suburban Massachusetts, material combinations that appear acceptable to date include:

- stainless steel with either aluminum or anodized aluminum;
- tin/zinc-coated products with galvanized steel; and
- aluminum with Al/Zn-coated steel.

Continuation of the test will show whether these materials remain compatible. Although corrosion of certain materials may be accelerated from galvanic action, the resulting corrosion rate could be low enough that issues are not observed during the product's service life. Other metal combinations tested may result in corrosion or staining problems in service, depending on how the materials are oriented for drainage on the building. **CS**

ADDITIONAL **INFORMATION**

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Abstract
Architectural design of building façades has become more complex, and buildings now commonly include multiple materials that may be incompatible over the long term. Even relatively standard rainscreen wall systems, such as aluminum panels supported by galvanized steel framing, can create durability issues. This article reviews the issues associated with galvanic corrosion in architectural applications, and presents initial findings of atmospheric corrosion testing between metals commonly used in building façades.

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